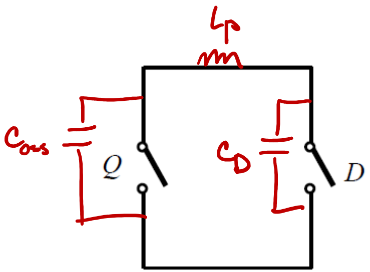
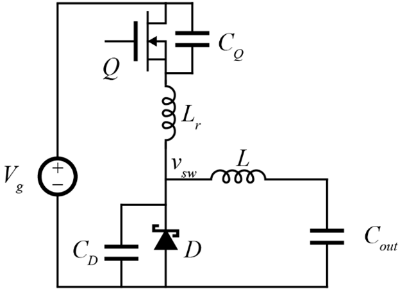
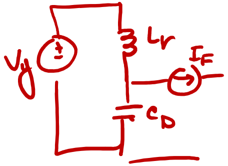
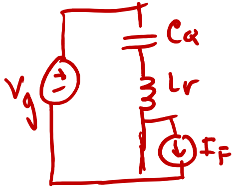
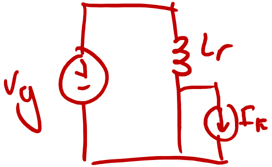
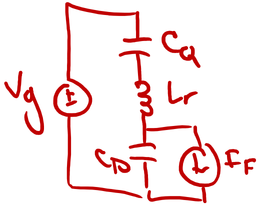
Wishlist: Multi-Resonant



ZVS-MR Buck



Conducting	Circuit	R_o
Q		$\sqrt{L_r/C_D}$
D		$\sqrt{L_r/C_Q}$
Q & D		X
X		$\sqrt{L_r/C_{eq}}$, $C_{eq} = \frac{C_Q C_D}{C_D + C_Q}$

W. A. Tabisz and F. C. Lee, "Zero-voltage-switching multi-resonant technique-a novel approach to improve performance of high frequency quasi-resonant converters," *Power Electronics Specialists Conference, 1988.*

Operating Modes

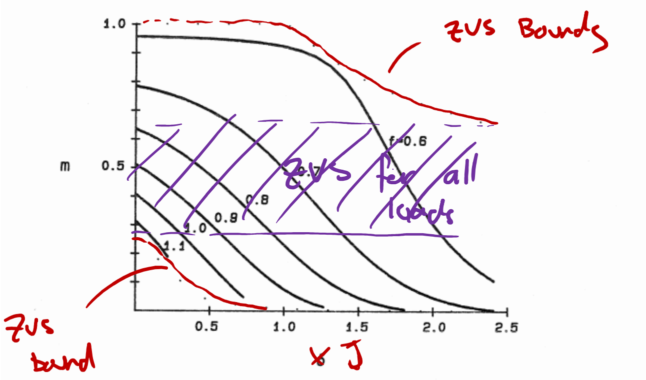
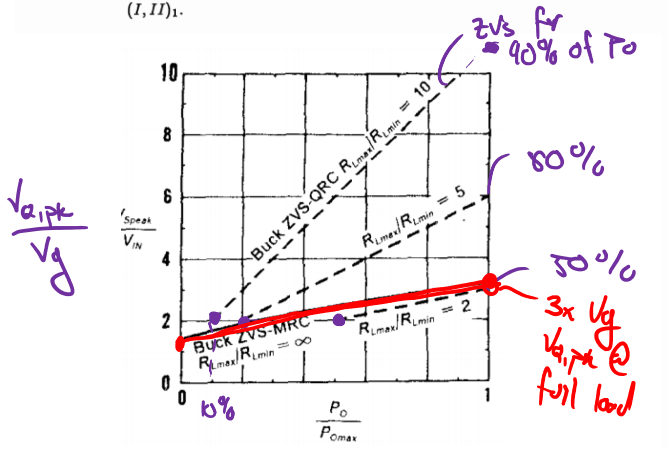


Figure 10.7: Load-to-output DC characteristics of a ZV-MR converter operating in modes $(I, II)_1$.



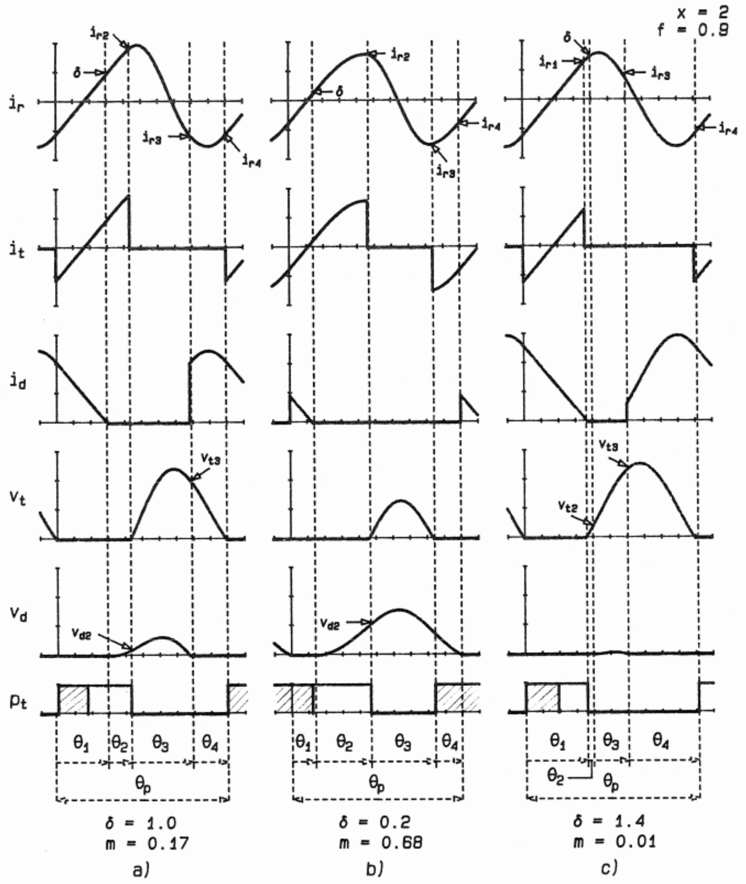
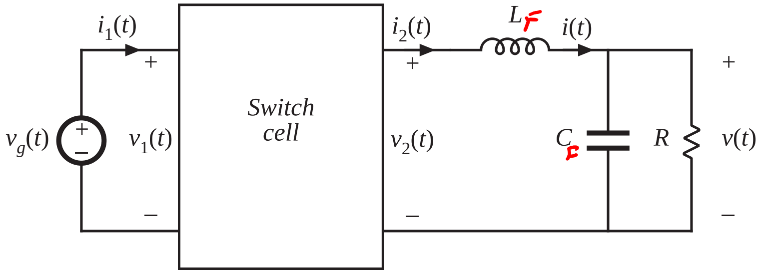
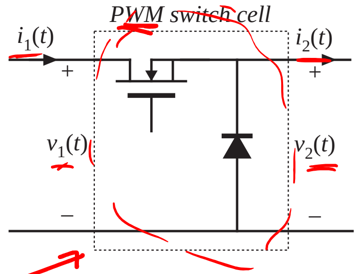


Figure 10.2: Typical waveforms for a ZV-MR converter operating in modes I_1 (a), II_1 (b) or III_1 (c).

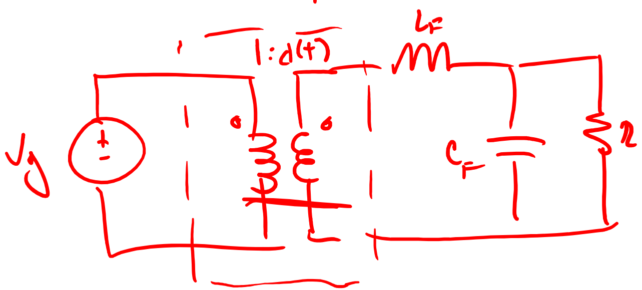
Identification of Resonant Switch





$$\langle v_2 \rangle = D \langle v_1 \rangle$$

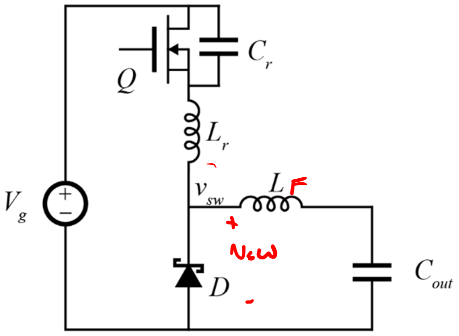
$$\langle i_1 \rangle = D \langle i_2 \rangle$$



Average, nonlinear model

Switching Cell Conversion Ratio

$$M = 1 - F P_{1/2}\left(\frac{1}{J_c}\right) = f(F, J_c)$$



For buck converter

$$M = \frac{\langle v_{out}\rangle}{\langle v_g\rangle} = \frac{\langle v_{sw}\rangle}{\langle v_g\rangle} = \text{switch cell conversion ratio}$$

$$M = \frac{\langle v_2\rangle}{\langle v_1\rangle} = \frac{\langle v_o\rangle}{\langle v_{in}\rangle}$$

For every other topology
μ = switch cell conversion ratio ($\neq M$ for non-Buck)

μ for resonant network is equivalent to d for PWM case

for any other parent topology,
take $M = f(D)$ from PWM analysis
replace $D \to \mu$
$M = f(\mu)$ for resonant switch implementation

Boost: $M = \frac{1}{1-D}$, PWM

ZVS-QR Boost

$M = \frac{1}{1-\mu}$, $\mu = 1 - F P_{1/2}\left(\frac{1}{J_c}\right)$

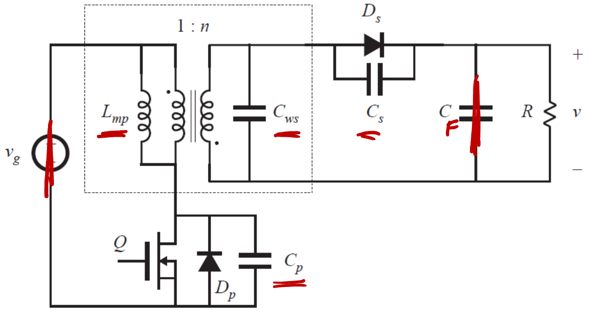
Conversion Ratios of Various Switch Cells

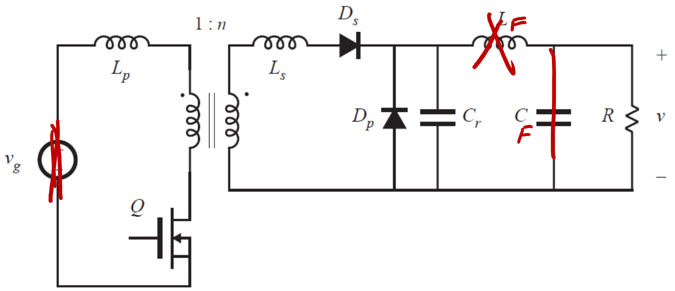
$$P_{1/2}(x) = \frac{1}{2\pi}\left[\frac{1}{2}x + \pi + \sin^{-1}x + \frac{1}{x}\left(1 - \sqrt{1 - x^2}\right)\right]$$

$$P_1(x) = \frac{1}{2\pi}\left[\frac{1}{2}x + 2\pi - \sin^{-1}x + \frac{1}{x}\left(1 - \sqrt{1 - x^2}\right)\right] \approx 1$$

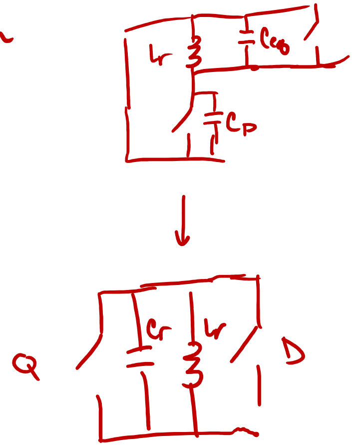
Switch Cell	Conv. Ratio μ	Current Range	Conv. Ratio Range	Requirements on Q
PWM	D	N/A	0≤μ≤1	
ZVS-QR (half)	$\mathbf{1 - FP_{\frac{1}{2}}\left(\frac{1}{J_L}\right)}$	$\mathbf{1 \le J_L \le \infty}$	**0≤μ≤1**	
ZVS-QR (full)	$1 - FP_1\left(\frac{1}{J_L}\right)$	$1 \le J_L \le \infty$	0≤μ≤1	Bidirectional voltage
ZCS-QR (half)	$FP_{\frac{1}{2}}(J_L)$	$0 \le J_L \le 1$	0≤μ≤1	Unidirectional Current*
ZCS-QR (full)	$FP_1(J_L)$	$0 \le J_L \le 1$	0≤μ≤1	

Resonant Switch Identification Examples



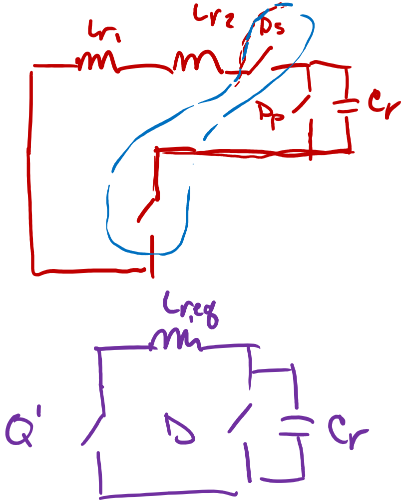


Flyback



$C_{eq} = n^2(C_s + C_{ws})$

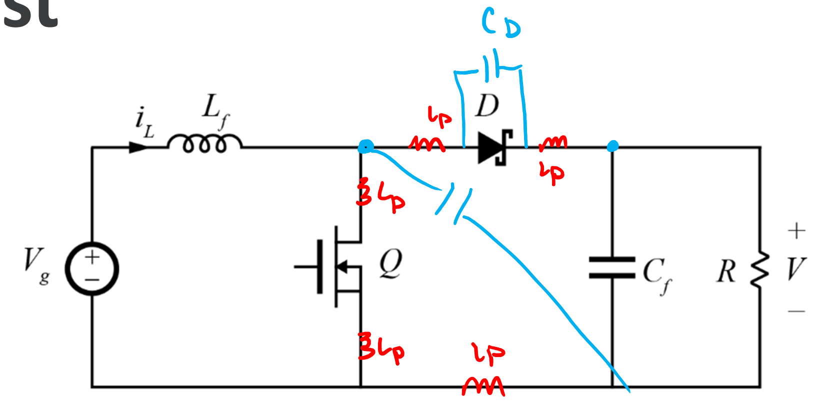
∴ this is the ZVS-QSW flyback



} voltage bidirectional switch

this is ZCS-QR forward converter

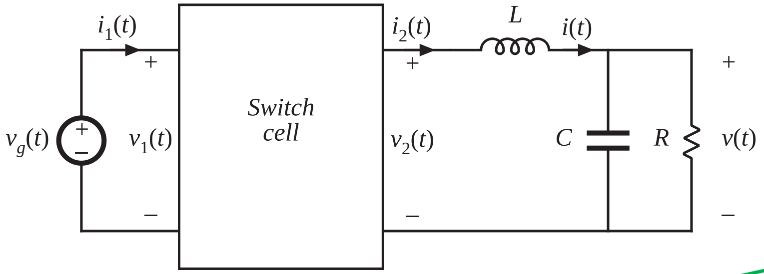
ZCS-QR Boost

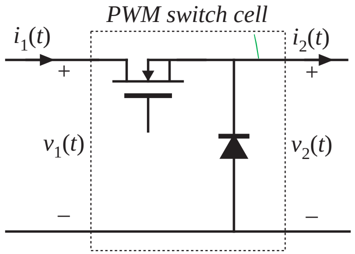


PWM Boost → $M = \frac{1}{1-D(t)}$

ZCS-QR Boost → $M = \frac{1}{1-\mu(t)}$

SSM - PWM Parent





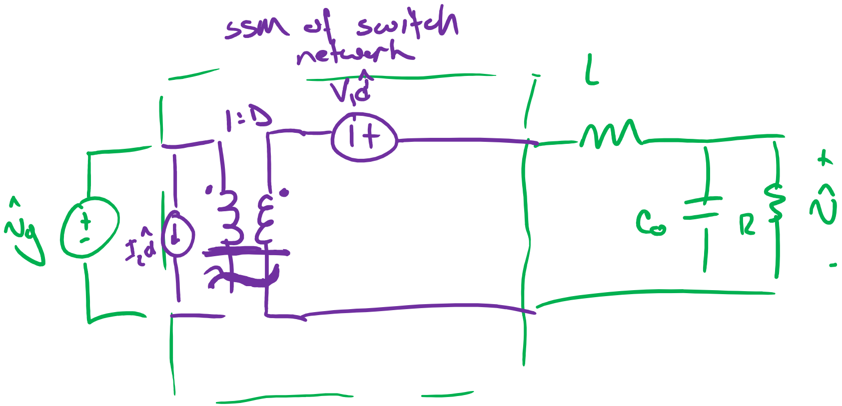
↓ Averaging

$$\begin{cases} \langle v_2 \rangle = d(t)\ \langle v_1 \rangle \\ \langle i_1 \rangle = d(t)\ \langle i_2 \rangle \end{cases}$$

↓ Small signal linearization

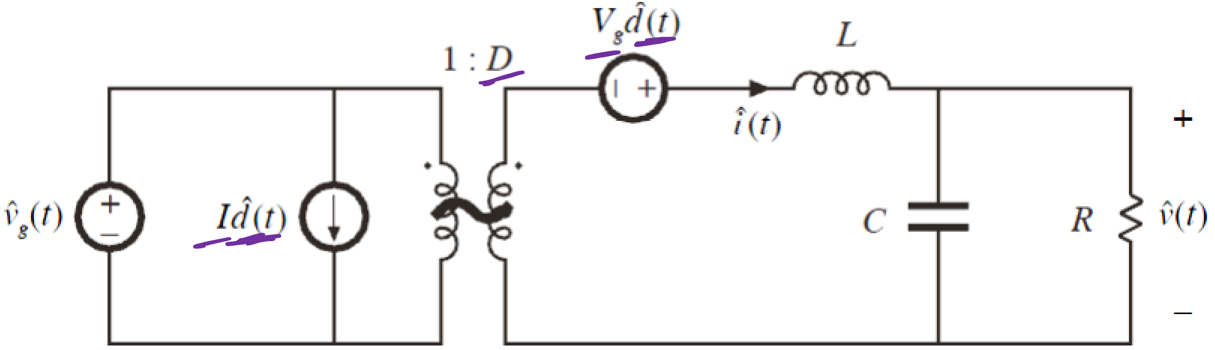
$$\begin{cases} \hat{v}_2 = D\hat{v}_1 + V_1\hat{d} \\ \hat{i}_1 = D\hat{i}_2 + I_2\hat{d} \end{cases}$$

← equiv circuit



SSM, PWM Case

Textbook, Fig.7.17(a)



ZVS-QR Switch Cell SSM

Replace $d(t)$ with $\mu(t)$

$$\mu = 1 - \frac{F}{2\pi}\left[\frac{1}{2J_L} + \pi + \sin^{-1}\left(\frac{1}{J_L}\right) + \sqrt{J_L^2 - 1} + J_L\right] \Rightarrow \mu = f(J_L, F) = f(i_L, v_g, f_s)$$

$$F = \frac{f_s}{f_0} \qquad J_L = \frac{I_L}{V_g}R_0$$

$$\mu = f(i_L, v_g, f_s)$$

$$\hat{\mu} = k_i\,\hat{i}_L + k_v\,\hat{v}_g + k_c\,\hat{f}_s \longrightarrow$$ small-signal linearization

Complete Solution

$$M = 1 - \frac{F}{2\pi}\left[\frac{\theta_1}{2} + \beta + J_2 + J_F\right]$$

$$M = 1 - \frac{F}{2\pi}\left[\frac{1}{2J_F} + \pi + \sin^{-1}\left(\frac{1}{J_F}\right) + \sqrt{J_p^2 - 1} + J_F\right]$$

→ same as 20.46 in 2nd Ed Fundamentals of Pwr Elec

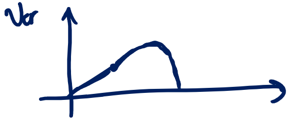
" 23.46 in 3rd Ed

$$M = 1 - F\,P_{1/2}\left(\frac{1}{J_L}\right)$$

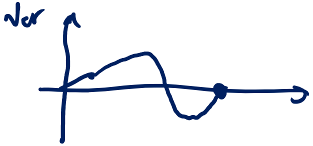
→ $\frac{1}{J_L} \leftrightarrow J_L$

$1 - F P_{1/2}(J_L) = M$ of ZCS-QR Buck

This is half-wave ZVS-QR Buck



Full-wave ZVS-QR Buck



→ Requires bidirectional voltage blocking Q